HYPER-X (X-43A) FLIGHT TEST RANGE OPERATIONS OVERVIEW

Jessica Lux-Baumann
Darryl A. Burkes
National Aeronautics and Space Administration
Dryden Flight Research Center
Edwards, CA

ABSTRACT

The Hyper-X program flew X-43A research vehicles to hypersonic speeds over the Pacific Ocean in March and November 2004 from the Western Aeronautical Test Range, NASA Dryden Flight Research Center, Edwards, California. The program required multiple telemetry ground stations to provide continuous coverage of the captive carry, launch, boost, experiment, and descent phases of these missions. An overview is provided of vehicle telemetry and distributed assets that supported telemetry acquisition, best-source selection, radar tracking, video tracking, flight termination systems, and voice communications. Real-time data display and processing are discussed, and postflight analysis and comparison of data acquired are presented.

KEY WORDS

Hyper-X, telemetry acquisition and display, flight testing, best source selection, Western Aeronautical Test Range (WATR)

INTRODUCTION

The Hyper-X program is an experimental flight research program intended to demonstrate advanced hypersonic technologies (reference [1]). The primary research objective is to flight-test an airframe-integrated scramjet, which could pave the way for high-speed aircraft and the next generation of reusable launch vehicles. The NASA Langley Research Center (LaRC, Hampton, Virginia) was the Hyper-X program lead, and the NASA Dryden Flight Research Center (DFRC, Edwards, California) led the flight test effort.

Three Hyper-X Research Vehicles (HXRV), collectively known as X-43A, were built for the Hyper-X program. All three vehicles were virtually identical; the main difference among them is internal scramjet engine flow paths. The first vehicle was intended to be flown to Mach 7 on June 2, 2001. It was lost along with its Pegasus® (Orbital Sciences Corporation, Dulles, Virginia) booster rocket approximately 48 seconds after launch because of a loss of control of the booster (reference [2]). The second vehicle was successfully flown to Mach 6.8 on March 27, 2004, and successfully demonstrated the in-flight operation of its scramjet. All of the goals for that mission, including positive acceleration of the vehicle by the scramjet, were achieved. The third and final mission of the program was flown to Mach 9.7 on November 16, 2004. This report discusses the flight test operations and results from flights 2 and 3.

The HXRV was an unmanned vehicle that measured approximately 12 ft long, and 5 ft wide, and weighed approximately 3,000 lb. A modified Pegasus® rocket booster known as the Hyper-X Launch Vehicle (HXLV), developed by Orbital Sciences Corporation of Chandler, Arizona, carried the X-43A to the test condition. The mated HXRV-HXLV stack was carried under the wing of the NASA B-52 aircraft, ship number 008. After the B-52 aircraft took off from Edwards Air Force Base (AFB), the stack was boosted to an altitude of approximately 40,000 ft at Mach 0.8 to make the drop, heading due west over the Pacific Ocean. A few seconds after drop, the HXLV rocket motor ignited, propelling the stack to a separation altitude of approximately 110,000 feet. After the HXRV separated from the HXLV, the cowl door on the HXRV opened, allowing for engine ignition and operation for approximately 10 seconds. After engine shutdown, the cowl door was closed, and an unpowered descent trajectory was flown to a splashdown in the Pacific Ocean. Figure 1 illustrates this flight trajectory. The flight 2 vehicle, with a maximum speed of Mach 6.8, traveled approximately 400 nmi downrange from the launch point. The flight 3 vehicle, with a maximum speed of Mach 9.7, traveled more than twice that distance, to approximately 850 nmi downrange, which presented greater challenges for data acquisition and tracking, as discussed in the section entitled “Telemetry Data Acquisition Results.”

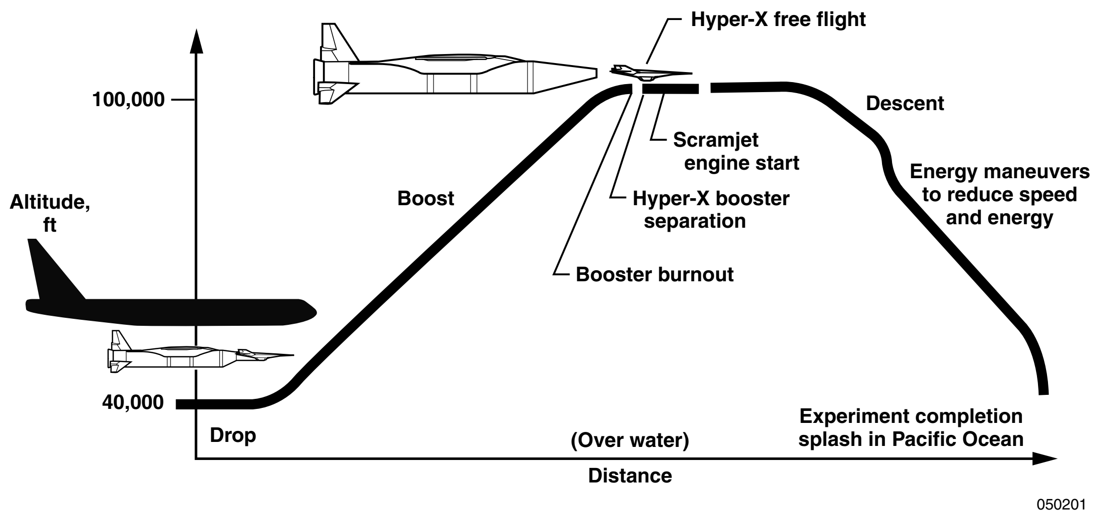

Figure 1. The X-43A flight trajectory.

The entire mission following drop from the B-52 aircraft until splashdown was carried out autonomously, and the HXRV was not recovered after splashdown. The primary purpose of these missions was to demonstrate scramjet engine operation, so the research (and telemetered data) from the postexperiment descent portion of the trajectory were considered of secondary importance. For mission safety and experiment monitoring, the Hyper-X program required continuous data communications links from the carrier B-52 aircraft, the HXLV, the booster-to-HXRV adapter, and the HXRV to the Western Aeronautical Test Range (WATR) at DFRC. These data communication links included telemetry, flight termination system (FTS) command transmission, precision radar tracking, and video transmission.

The Hyper-X operational concept called for DFRC range control during ground operations and in the local Edwards AFB airspace. Control was transitioned to the Naval Air Warfare Center Weapons Division (NAWC-WD) Sea Range when the B-52 aircraft with X-43A stack crossed into the NAWC-WD airspace over the Pacific Ocean. The test conductor (TC) for the NAWC-WD communicated directly with the range control officer (RCO) at DFRC regarding X-43 telemetry, FTS, radar, video, and voice communications for the mission.

PROGRAM INSTRUMENTATION

For Hyper-X missions, four telemetry streams were transmitted to ground assets for real-time analysis and display. In addition, radar data were reformatted using WATR assets into a pulse code modulation (PCM) stream for time correlation with PCM telemetry data. Table 1 summarizes these streams.

Table 1. The X-43 telemetry requirements.

Source	Data rate	Frequency	Input code	Transmit power (Watts)
HXRV Primary	1.0 Mbps	2279.5 MHz	RNRZ-L	20
HXRV Aft (Redundant stream)	1.0 Mbps	2283.5 MHz	RNRZ-L	10
HXLV	1.92 Mbps	2237.5 MHz	RNRZ-L	5
B-52	125 Kbps	1480.5 MHz	NRZ-L	5
Radar	160 Kbps	N/A		

The HXRV primary, HXLV, and B-52 aircraft streams were transmitted during the entire mission. The HXRV aft transmitter antenna was blocked when the HXRV was mated to the HXLV, so it was activated only after separation of the HXRV vehicle from the HXLV vehicle. For redundancy, the aft antenna transmitted the same PCM stream as that of the primary source, intended for use as a backup if the primary transmitter failed during the boost, experiment, and descent phases of the mission.

For time-space positioning information (TSPI) data, the B-52 aircraft and HXRV were equipped with C-band transponders. The HXLV had no C-band transponder, so a skin echo track was required.

A DFRC F/A-18 chase aircraft tracking the B-52 aircraft and stack transmitted one L-band video stream throughout the captive mission and during the boost phase. The B-52 aircraft transmitted one S-band video stream, which toggled between a front view and an aft view of the stack under the B-52 wing. The B-52 aircraft also had the capability to reradiate the F-18 chase aircraft video stream on the S-band to allow the Sea Range assets to receive the chase video.

The HXLV-to-HXRV adapter transmitted two S-band video streams; however, because of the mating configuration, these camera lenses were covered until the HXRV-HXLV separation event. The expected duration of video was only a few seconds. As such, to ensure that the recording of the video transmission for the separation event would not be missed, these frequencies were recorded for a window of time around the expected separation event.

An FTS was active on the HXLV for emergency command termination during the boost stage over the NAWC-WD Sea Test Range. Preprogrammed tone sequencing was defined for the termination process. Program requirements called for the Missile Flight Safety Officer (MFSO) at Pt. Mugu to terminate the HXLV after the separation of the HXRV. For flight 2, termination was planned when the launch vehicle descended to an altitude of 50,000 ft. For flight 3, termination was planned for 10 seconds after the separation event.

Voice communications support requirements included the reception of, and transmission from mission control on, the following frequencies: B-52 primary UHF, B-52 backup UHF, and safety chase VHF.

DATA ACQUISITION AND TRANSMISSION

For Hyper-X missions, a fiber optic network and the Navy Ranges Microwave System (NRMS) were used to transmit all voice, radar, telemetry, and video data between the NAWC-WD Sea Test Range and the DFRC WATR. Figure 2 provides an overview of the data transmission, from NAWC-WD assets, through the NRMS to Edwards AFB, and into WATR assets.

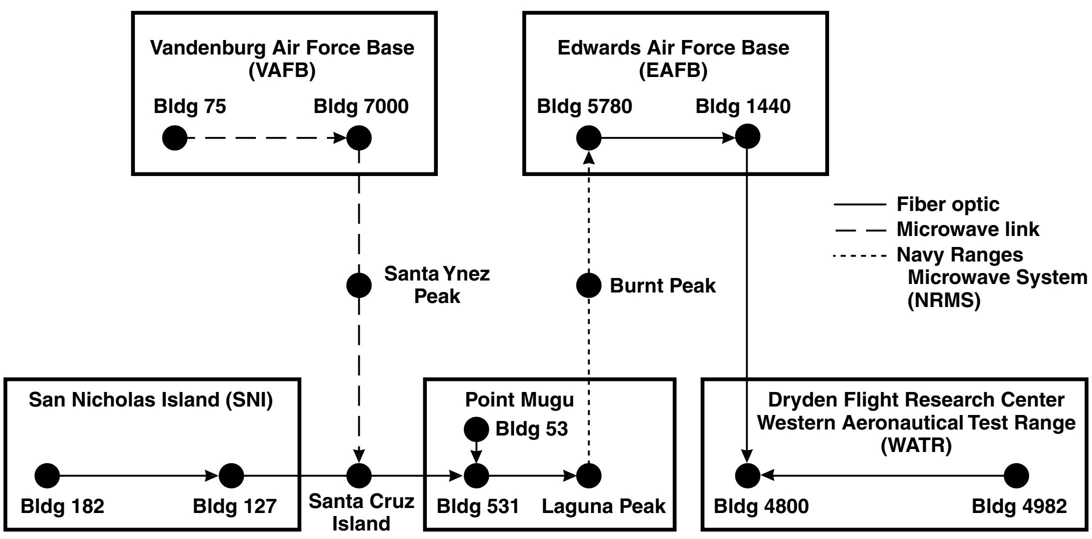

Figure 2. The X-43A data transmission.

Western Aeronautical Test Range Support Assets

The WATR at DFRC has the following assets: telemetry tracking and receiving ground stations, radar tracking systems, audio and video communications systems, FTS command transmit systems, real-time processing and display systems, mobile systems, and control rooms. The Hyper-X program utilized nearly all of the WATR assets for its hypersonic missions.

The WATR telemetry tracking stations supporting the Hyper-X missions included the 7-meter Triplex system and the 12-foot Rooftop system. The Triplex was able to receive high-quality telemetered data for the HXRV well past the boundaries of the Edwards AFB airspace and into the NAWC-WD Sea Range. The Rooftop system has a more limited range and was used primarily for telemetry tracking of the stationary B-52 aircraft with the mated HXRV and HXLV during the hours of ground preflight operation on the Edwards AFB ramp.

The WATR operated both of its C-band range instrumentation radars (RIR)-716, the Radar 34 and Radar 38 systems, in support of Hyper-X missions. In addition to radar time-space positioning assets, the WATR also operates a differential global positioning system (DGPS) ground station, which is utilized postmission for correlation with the onboard B-52 GPS data.

The long-range optics (LRO) camera at the WATR was used for viewing the Hyper-X missions in the local airspace. During ground preflight operations on the Edwards AFB ramp and during taxi, a number of fixed camera systems were used to view the operations from different angles. The WATR mobile video van was also deployed to cover any remote testing areas with real-time video provided to the control room by means of microwave links. The WATR also received and recorded downlinked video from the B-52 aircraft and the F-18 chase during ground operations and while in the local airspace.

To ensure HXLV FTS system integrity, before the B-52 aircraft takeoff, ground checks were performed by the range safety officer (RSO) at DFRC, using WATR systems. The FTS then was deactivated, to be reactivated later by the Pt. Mugu MFSO for in-flight FTS checks by means of the Sea Range assets.

The WATR assets were used to transmit and receive UHF and VHF voice communications among the B-52 aircraft, the F-18 chase aircraft, and mission control. In addition, local DFRC communications networks were required for communications between research engineers, RSOs, RCOs, and WATR asset operators, and operators for the DFRC-LaRC data transmission system.

All four mission control centers (MCCs) of the WATR were utilized for Hyper-X missions. The MCCs at DFRC provide consoles for range control, mission control, flight operations, range safety, flight director, and research engineers. The MCC capabilities include stripchart recorders, video monitors, communication panels, and high-powered graphics data display workstations. The global real-time interactive map (GRIM), DFRC in-house software, is provided in the MCCs for ground-tracking of flights. This software was heavily utilized on the Hyper-X missions to ensure that the B-52 aircraft hit all required waypoints on the flight out to the drop point and to time the predrop sequences that occurred during the captive carry portion of the mission.

The MCC2 was staffed with mission control, range control, flight operations, range safety, project management, the flight director, and research engineers from the Flight Systems, Propulsion, Instrumentation, Controls, and Structures disciplines. The MCC3 was staffed with Aerodynamics and Structural Dynamics project engineers. The MCC4 was staffed with Orbital Sciences

Corporation engineers that monitored HXLV health. The MCC1 was used an auxiliary monitoring room for program management, guests, and a live Public Affairs broadcast on NASA television.

For Hyper-X, the WATR developed a capability to transmit a subsampled subset of the HXRV telemetry stream from DRFC to a mission monitoring room at LaRC. This 1.2-Mbps data stream was transmitted securely over the Internet to LaRC.

Naval Air Warfare Center Weapons Division (NAWC-WD) Sea Range Support Assets

The Naval Air Warfare Center Weapons Division (NAWC-WD) Sea Range had a series of distributed assets supporting X-43A data acquisition. Redundancy was built into the data acquisition plan, so that there were no single-point-failure assets recording the telemetry. An overview of the Air Force/NAWC-WD support sites is provided in Figure 3. Sites supporting the Hyper-X mission include:

- Vandenburg Air Force Base (VAFB)
- San Nicholas Island (SNI)
- Pt. Mugu mainland (Pt. Mugu)
- Laguna Peak, Pt. Mugu, CA (LP)
- NP-3D Orion aircraft (P-3)

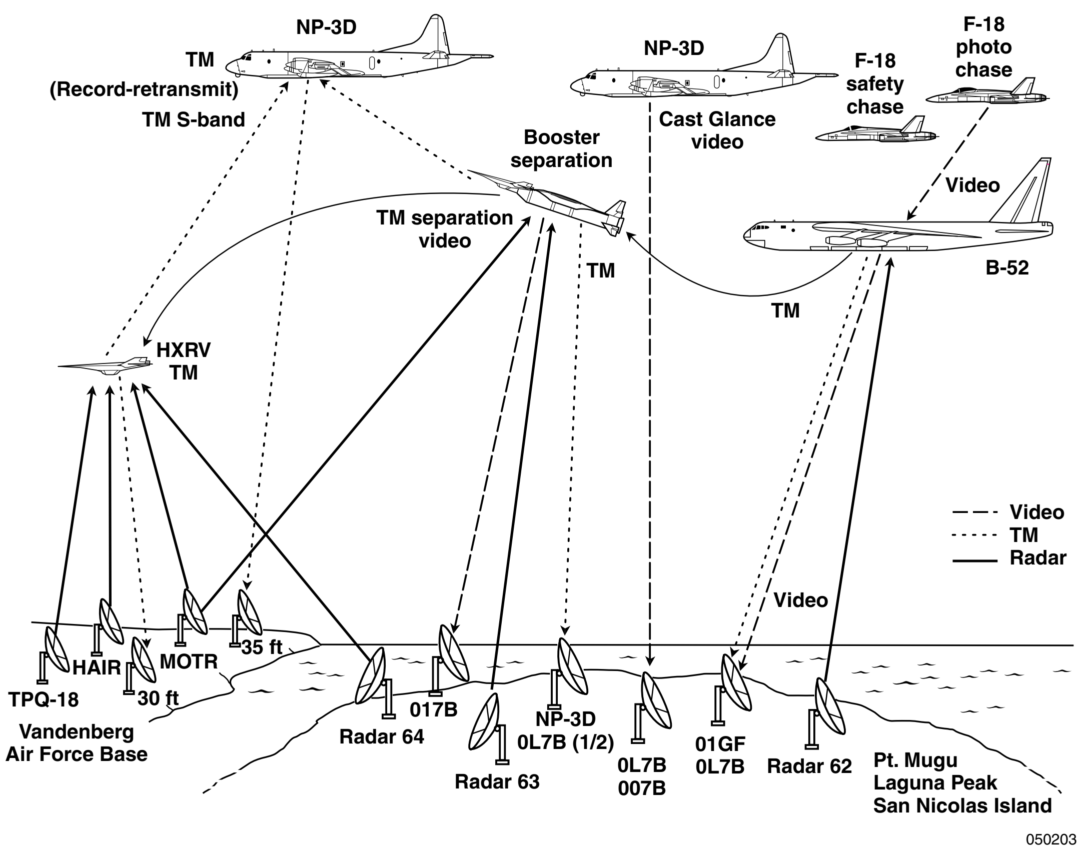

Figure 3. The NAWC-WD Sea Range support assets for X-43A.

Telemetry data were collected from the various sites (VAFB, SNI, Pt. Mugu, P-3 aircraft, and LP) and sent to the Pt. Mugu mainland for best source processing. The HXRV data were processed using the manual best source selector, and HXLV and B-52 aircraft data were processed using an automated best source selector. The manual best source selector has an operator who manually chooses the best source based on the frame sync status. The HXRV data stream initially was run through the automated best source selector, but during the flight 2 captive carry mission, the automated equipment caused the quality of the telemetry stream to degrade (subframe sync losses). As such, its use was discontinued, and the manual best source selector was utilized for both flights 2 and 3.

The P-3 aircraft (Lockheed Martin Corporation, Bethesda, Maryland) received, recorded, and retransmitted all three S-band sources radiating from the HXLV and HXRV. The VAFB 30-ft telemetry antenna tracked the HXRV. For flight 2, the VAFB 35-ft telemetry antenna tracked the P-3 aircraft, so that P-3 data could be relayed in real time to the MCC at DFRC. For flight 3, because of the longer western downrange travel of the Mach 10 X-43A vehicle, the P-3 aircraft was out of range for real-time transmission to VAFB. As a result, the VAFB 35-ft telemetry antenna tracked the HXRV as a redundant source to the 30-ft telemetry antenna. The P-3 aircraft recorded data onboard for postmission analyses, without real-time display capability. For flight 3, data loss was expected in the control room during the descent portion of the mission (following the conclusion of the primary research objective, the engine experiment). Program requirements called for a 24-hour turnaround for the onboard P-3 recordings of the HXRV telemetry stream, so that researchers at DFRC could analyze vehicle performance during the final descent of the vehicle.

Radar assets from the NAWC-WD Sea Range were assigned as follows:

- Pt. Mugu fixed point sensor (FPS)-16 Radar 71: B-52 beacon track
- Pt. Mugu FPS-16 Radar 72: HXRV beacon track (flight 3 only)
- SNI Radar 64: HXRV beacon track
- SNI Radar 63: HXLV skin track
- VAFB multiple object tracking radar (MOTR) M01 Radar: HXRV beacon track
- VAFB MOTR M02: HXLV skin track (switching to HXRV beacon track during experiment)
- VAFB TPQ-18 R14: HXRV beacon track
- VAFB high-accuracy instrumentation radar (HAIR) R13: HXRV skin track (flight 2 only)

In addition, one NASA radar transmitted a B-52 aircraft track to NAWC-WD to assist in initial NAWC-WD acquisition of the B-52 beacon track as it transitioned into the Sea Range airspace.

All VAFB and SNI radars sent radar data to Pt. Mugu in real time, where data were recorded and transmitted to NASA DFRC in real time. The VAFB radars collected enhanced data for possible customer posttest requirements. All radar sites provided weather data (pressure, temperature, and either dew point, humidity, or wet bulb temperature) taken before and after tracking.

The NAWC-WD Pt. Mugu received, recorded, and transmitted the three S-band and video sources to NASA DFRC. Three video streams were sent to NASA DFRC (B-52 and chase aircraft video, and adapter no.1 video) over a video codec and two video streams (adapter no.1 video and adapter no. 2 video) over a DS-3 Mux video channel. This setup remained fixed during the mission, even though the two adapter videos transmitted a blank screen for the captive and boost portions of the mission, transmitting for only a few seconds during the separation event.

Flight termination command transmit capability was provided at Laguna Peak: 425 MHz (1 kW), San Nicolas Island (1 kW), and the NP-3D aircraft (500 W power). The MFSO at Pt. Mugu had command of the FTS system when the B-52 aircraft entered the NAWC-WD Sea Test Range.

The voice communications included UHF and VHF radios (with remote key capability) and voice networks for the RSOs (FTS and airspace coordination), RCOs (telemetry, voice, video, and radar coordination), and Hyper-X flight test coordination between the Point Mugu and DFRC TCs and pilots.

TELEMTRY DATA ACQUISITION RESULTS

The WATR received digital tape cassettes and 14-track analog reel tapes from the VAFB NAWC-WD telemetry sites for the Hyper-X missions. At the WATR, each tape was played back, and the cumulative number of mainframe sync losses for the period of drop through splashdown was calculated. The best sources have the fewest number of mainframe sync losses for the period of interest. For flight 2, telemetry sources were able to track the HXRV to 40 ft above sea level. For flight 3, telemetry sources tracked the HXRV to approximately 900 ft above sea level before loss of signal (LOS). Telemetry tracking of both missions was considered a complete success, because the primary research objective (the scramjet engine experiment) had redundant telemetry recordings, and the secondary research objective (the unpowered descent into the Pacific Ocean) also was recorded down to sea level.

For flight 2, for the duration of the period from drop to splash-down in the Pacific Ocean, the P-3 onboard data recording was the best source for telemetered HXRV data, both on the 2279.5 MHz (HXRV primary antenna) and the 2283.5 MHz (HXRV aft antenna) frequencies.

The flight 2 best source engineering data set was constructed from two segments of data: (1) the real-time recording at the WATR for the ground operations and captive carry portions of mission, and (2) the P-3 onboard recording for the drop, boost, separation, experiment, and descent phases of the mission. The two data sets were spliced together during a period before the drop of the HXRV-HXLV stack, so that the entire mission post-drop was available from one source. Most postflight analyses were performed on segment 2 of the flight data. Therefore, the fact that the two segments do not have a unified time source was not a concern, because analyses are not likely to span the two segments.

For flight 3, no single best source existed for the post-drop phase of the mission. The VAFB 35-ft dish was expected to provide the best data for the mission; however, that source was inferior to the VAFB 30-ft dish. The 30-ft dish was the best ground-based source until LOS during the descent portion of the mission, when the HXRV was at an altitude of approximately 92,000 ft and a longitude of -128.8 degrees. This VAFB 30-ft dish, however, had a 13-second LOS event during the boost phase of the mission. During that 13-second LOS event, the SNI antenna was the best ground-based source.

During flight 3, because of the downrange distance of the P-3 aircraft, no data were transmitted back to VAFB in real time, so the P-3 recordings were used only for postflight analyses. The P-3 aircraft started to record high-quality data as expected before the separation event, so that dual telemetry coverage (VAFB 30-ft dish and P-3 aircraft) was available for the engine experiment portion of the mission. Because the engine experiment was the primary focus of the entire program, telemetry recordings for this phase of the mission could not be single-string. The P-3 aircraft is the only source for descent data following LOS from the VAFB 30-ft dish.

The best source data set for the flight 3 mission was constructed from three segments of data: (1) the real-time recording at the WATR for the ground operations and captive carry portions of mission (ending 10 minutes before the drop event), (2) the SNI recording for the drop, boost, cowl-open, engine experiment, and cowl-closed phases of the mission, and (3) the P-3 onboard recording for the remainder of the descent portion of the mission. Despite the fact that the VAFB 30-ft dish provided slightly better data quality for the boost phase of the mission, the SNI recording had to be used because of the 13-second LOS event.

These three sources have separate, nonaligned timing sources and, unlike in the case of flight 2, analyses are likely to span segments 2 and 3 of the data set. A single, unified, time-aligned time history data set was required for flight 3 postflight research analyses. This data set was generated by first establishing the segment (1) WATR timing source as the baseline for the entire mission. The 100 Hz HXRV telemetry data stream has several discrete event parameters, such as B-52 aircraft release command, the HXRV-HXLV separation command, a cowl brake command, and several maneuver-complete commands. These discrete events were located in each of the three data sources, and the time stamp offset between each source and the baseline was calculated. When the average time stamp offset between sources was calculated, the time vectors for segments 2 and 3 were unilaterally skewed by this offset to generate a unified time history data set. The average offset from the baseline WATR timing source for the VAFB 30-ft dish, SNI, and P-3 data sources was approximately 0.037 seconds. The difference is likely the result of delays in the transmission of data across the data links between the NAWC-WD and the WATR.

For each mission, when a final best source data set was constructed from the segmented telemetry sources, time history data sets were provided to research engineers on data storage systems at DFRC. In addition, time history data sets were sent to research teams at LaRC for dissemination. The WATR provided a 24-hour turnaround on preliminary data sets following each mission.

CONCLUSION

The X-43A vehicle telemetry and range support requirements and interfaces have been described in detail. Extensive coordination occurred between the Western Aeronautical Test Range (WATR) and Naval Air Warfare Center Weapons Division (NAWC-WD) to plan for continuous coverage of the flight data, position information, video sources, and voice communications. Radar tracking, video tracking and transmission, flight termination systems, and voice communications for the X-43A program all performed according to plan for both flights 2 and 3. Real-time data provided by the WATR and NAWC-WD assets were successfully transmitted into the NASA Dryden Flight Research Center (DFRC) mission control centers to facilitate all safety and mission success decisions prior to launch. Telemetry tracking of both missions was considered a complete success, because the primary research objective (the scramjet engine experiment) had redundant telemetry recordings, and the secondary research objective (the unpowered descent into the Pacific Ocean) also was recorded to sea level, with minimal loss of signal. In addition, a real-time data relay for limited concurrent mission monitoring at NASA Langley Research Center (LaRC) was effectively demonstrated. The WATR successfully distributed postmission data products to researchers at DFRC and LaRC, after facing unique challenges in time-aligning separate data sources for the Hyper-X Research Vehicle data for flight 3.

The two X-43A missions have demonstrated an operational hypersonic corridor for missions originating from Edwards Air Force Base and terminating in the Pacific Ocean in the NAWC-WD Sea Range. Future vehicles of hypersonic speeds can utilize the corridor and data relay system described in this report for continuous coverage during flight test operations.

REFERENCES

1. Reubush, David, Nguyen, Luat, and Rausch, Vincent, “Review of X-43A Return to Flight Activities and Current Status,” AIAA-2003-7085, December, 2003.

2. X-43 Mishap Investigation Board, “Report of Findings: X-43A Mishap,” vol. 1, May 2003 http://www.nasa.gov/pdf/47414main_x43A_mishap.pdf.